UNDERWATER PROCESSING WITH AND WITHOUT ADDED CALCIUM INFLUENCES SHELF LIFE QUALITY OF FRESH-CUT CANTALOUPE

O. LAMIKANRA[1], K.L. BETT-GARBER[1,2], M.A. WATSON[1] and D.A. INGRAM[1]

[1]*United States Department of Agriculture*
Agricultural Research Service
Southern Regional Research Center
1100 Robert E. Lee Boulevard
New Orleans, LA 70124

Received for Publication February 15, 2008
Accepted for Publication January 31, 2009

ABSTRACT

The effect of processing cantaloupe melon while submerged underwater on the fresh-cut fruit quality was determined. Total plate, coliform, yeast and mold counts were lower in underwater processed fruit after 1 day storage, but were not significantly different after 7 days. Dissolved calcium in the treatment water reduced microbial growth in cut fruit over the storage period of 14 days. Sensory evaluation indicated increased fruity/melon intensity and decreased rancid/painty intensity of underwater processed fruit. Peroxidase activity increased in underwater processed fruit and presence of calcium in treatment fluid elevated this effect. Underwater processed fruit respired less during storage at 10C. Results indicate an increased defense response as a result of underwater processing that is enhanced by the presence of calcium ions in the treatment fluid.

PRACTICAL APPLICATION

The increased demand for fresh-cut fruit has lead to the need for longer shelf life quality. This research details a novel method of boosting the quality of fresh-cut cantaloupe utilizing novel cutting methods and GRAS processing aids that disrupt the normal cycle of senescence in wounded fruit. These methods can be used by the small processor or adapted for large processors.

[2] Corresponding author. TEL: 504-286-4459; FAX: 504-286-4419; EMAIL: karen.bett@ars.usda.gov

DOI: 10.1111/j.1745-4557.2010.00315.x

INTRODUCTION

Wound signals are triggers of plant senescence and product deterioration. One of the earliest processes following wounding is the depolarization of membrane potential in cells close to the site of wounding (Shimmen 2001). The slow transient depolarization requires turgor pressure and is usually the first step in a chain of reactions that could be propagated over large distances in plant tissues. The message from the killed cells essentially sends information that turgor pressure has been lost. This injury-induced loss of tension allows water to move into adjacent living cells, where increased turgor activates pressure-sensitive channels (Stankovic *et al*. 1997). It has been suggested that systemic changes in extracellular electric potential that follows localized wounding may be triggered by a hydraulic wave (Malone and Stankovic 1991; Stahlberg and Cosgrove 1995). Herde *et al*. (1998) found that a signal leaving the damaged tissue between 2 and 4 min after wounding was responsible for a significant amplification of Pin2 gene expression in tomato plant, and appears to decrease turgor pressure which, in turn, increases ionic movements across cell membranes. We are speculating that this happens in all plant tissue, including the fruit

Most treatments to preserve sensory quality and shelf life of fresh-cut fruits and vegetables are carried out after cutting (Garcia and Barrett 2002). These treatments are thus applied after wound responses and the deteriorative process have been initiated. Intervention in the wound-signaling mechanism could alter tissue senescence and, consequently, product deterioration rate, which could improve shelf life of minimally processed fruits. The concept of simultaneous cutting and washing of leafy vegetables has been reported (Beguin *et al*. 1996; Caridis *et al*. 2002). The focus of these processes is to rapidly wash away internal liquids of injured cells containing enzymes that could catalyze undesirable deteriorative actions such as browning. Although enzymatic browning is not a significant consideration in cantaloupe melon (Lamikanra and Watson 2001), there is a wounding issue. A potential advantage of processing underwater is that processing aids can be dissolved in the water and act on the fruit right as it is cut. Calcium is well known for delaying plant senescence and makes a good processing aid, and is also involved in wound signal transduction pathways (Poovaiah 1993). This is largely associated with its stabilizing influence on cell membranes (Ferguson 1984; Lamikanra and Watson 2004). Lamikanra and Watson (2007) found that calcium did not increase firmness much during heat treatment of whole melons. In this report, we investigate the effect on sensory quality and other indicators of quality deterioration during storage of fresh-cut processing of cantaloupe melon while submerged under water compared to cutting in air. We also determined the effect of dissolved calcium on the sensory quality and shelf life

of underwater processed fresh-cut cantaloupe melon. The rationale is that processing in this manner allows the maintenance of turgor upon cutting of the fruit and allows for the washing away of reactive enzymes that will start the undesirable biochemical reactions associated with cutting fruit.

MATERIALS AND METHODS

Fruit Preparation

Cantaloupe melon (*Cucumis melo* L. var. *reticulates*) destined for the fresh fruit market, supplied by Del Monte Fresh Produce Co. (Coral Gables, FL), and was delivered at 4C. Before processing, the fruit was cleaned in water at 4C containing sodium hypochlorite (100 ppm free chlorine) at pH 6.5 and scrubbed with a brush. The processing was carried out underwater using a fruit submersible tank constructed at the ARS-Southern Regional Research Center. Two separate experiments were accomplished; one was cut in chlorinated water and the other had 0.5% calcium chloride added to the cutting water. Submerged fruit in chlorinated water (7 ppm free chlorine; 4C with pH adjusted to 6.5 with citric acid) was cut longitudinally into two halves. One half was processed under water while the other half was removed from the tank for processing in open air at 4C. A thin slice (~1 mm) was cut from the exposed flesh of the portion processed in air. Both halves were further processed, identically, except for the presence of water. The seeds were removed, and each half was cut longitudinally into four sections. Each section was then peeled and a thin slice (~1 mm) was removed from the seed cavity surface. Bite-sized chunks (approx. 3–4 g) were cut from the sections. Underwater cut fruit were placed in salad spinners and spun gently to remove dripping water from the fruit. For the nonsensory tests, three melons were processed for each treatment. Approximately 300 g of cubes from each melon were placed into 24-oz (about 1 L) low-profile Juice Catcher containers (SRW-24-JC; Winkler Forming Inc., Carrollton, TX), and stored at 10C. This temperature was chosen to increase the stress on the melons that results in pushing the quality to the limits. Samples were evaluated at days 1, 7, 10 and 14, because most of the change occurs after 6 days. Nine melons were processed individually for sensory evaluations using this procedure. Sensory samples were comprised of six melon cubes stored in 5 cm fruit cups a (#381200; Rock-TN Company, Norcross, GA) labeled with the panelist's name and a three-digit random number and stored at 10C. If the samples displayed visible microbial growth, they were evaluated for aroma and not tasted by the sensory panel members. Good manufacturing practices and best possible sanitary conditions were strictly adhered to during processing and all handling stages.

Microbial Assays

Microbial assays were performed by Silliker Inc. (Grand Prairie, TX). On each sampling day, two sets of fruit (50 g) for each treatment in 5 cm fruit cups were cooled down to 4C, placed on ice packs in Styrofoam containers previously cooled down to the same temperature and shipped overnight. Fruit pieces were homogenized with sterile water, serially diluted, and overlaid onto Aerobic Count Petrifilm plates, Petrifilm Coliform plates, and Yeast and Mold Petrifilm plates (3M Co., St. Paul, MN). The coliform counts were done after 24 h of incubation at 35C while yeast and mold counts were taken at 120 h. The total aerobic plate counts were done after incubation for 48 h at 35C. For lactic acid bacteria determination, the fruit was initially blended with 0.1% peptone, serially diluted and overlaid onto deMan Rogosa Sharpe plates. Plates were then incubated at 30C for 120 h before colonies were counted.

Color Analysis

Color was recorded as tristimulus L^*, a^*, b^* values using a HunterLab DP 9000 colorimeter (D25 A/L type optical sensor) (Reston, VA) using $^1/_2$ inch diameter specimen port. The standard observer was 2° and illuminant was C (the standard CIE daylight illuminant). The system was standardized using the white and black tiles provided by HunterLab for this instrument. Randomly selected samples (three fruit chunks per container from three different melons [$n = 9$]) on each storage day by treatment were measured on the cut side of the melon chunk (not on the rind or seed cavity sides).

Sensory Evaluation

The sensory panel was made up of seven panelists trained in descriptive analysis of cantaloupe melon. Each panel member monitored one of the individually processed fruit from processing day until day 14 of storage. Six flavors (fruity/melon, sweet aromatic, musty, fermented, sweet, sour) and three texture attributes (surface wetness, hardness and moisture release) were evaluated (Bett 2002). The translucent/water soaked appearance descriptor was developed at the Southern Regional Research Center, New Orleans, LA. The definition is: The appearance of fruit tissue that has lost opaqueness and is beginning to look water soaked. The intensity references are chalk = 0.0, copy paper = 1.0, Parafilm = 6.0, clear Knox Gelatin = 13.0, and Saran Wrap = 15.0. Five cubes equilibrated to 24C were placed in glass custard cups and covered with inverted watch glasses that extended at least 13 mm over the edge of the cups. The cups were labeled with three-digit random numbers. During evaluations, panelists vented the lids to allow the headspace to enter the nose. Intensities of the various aromas emitted from the samples were

assessed. After aroma evaluations, panelists performed flavor and texture analysis by mouth. Intensity was rated on a 0–15-point anchored scale with 0 being not detectable and 15 being more intense than most foods (Meilgaard *et al*. 2007). Panelists used filtered water and unsalted crackers between samples to cleanse their palates. Sensory analysis was conducted under red lights to discourage preconceptions associated with food coloration. A warm-up sample of similar fruit was presented first to reduce the first sample position bias. Thereafter, the experimental samples were presented monadically in random order at 10 min intervals within a session All panelists received samples in the same order for a given storage day.

Peroxidase Enzyme Activity

Cut fruit (300 g) was homogenized with cold acetone (500 mL; –20C) in a Waring blender for 30 s. The blended mixture was further homogenized using a Tekmar™ Tissumizer for 30 s. The homogenate was then vacuum-filtered through a Whatman no. 4 filter paper to remove the residue and successively homogenized in cold acetone and filtered until a colorless filtrate and a white powder was obtained. The powder was allowed to dry under a stream of air at room temperature. Enzyme extraction from the acetone powder (0.5 g) was carried out by homogenizing the powder with mixture of phosphate buffer (0.05 M; pH 8.0, 30 mL) and Triton X-100 (2%). The homogenate was centrifuged at 12,000 × g and 0C for 20 min. The resulting supernatant was used for peroxidase activity assays.

Peroxidase activity was assayed in a buffer consisting of 0.02 M Na_2HPO_4 and 0.08 M NaH_2PO_4, 20 mM guaiacol 4 mM H_2O_2, enzyme extract (10 μL), pH 6 in a total volume of 3 mL. The reaction mixture was transferred into a cuvette and incubated at 50C. Absorbance readings at 470 nm between 30 and 90 sec of the reaction time were used to determine the initial rates of reactions. "Relative activity unit" was defined as the amount of enzyme that caused an increase in absorbance by 0.001 units/min under the test conditions (Lamikanra and Watson 2000, 2007).

Determination of Respiration

Cut fruit from each treated melon (50 g) was placed into separate jars (0.5 L) fitted with air-tight lids equipped with rubber septums and stored at 10C. Analysis for CO_2 and O_2 gas in the headspace was carried out by withdrawing a sample of gas (8 cm^3) with a needle syringe attached to Mocon Pack Check 650 analyzer (MOCON\Modern Controls Inc., Minneapolis, MN) through the rubber septum of the respective jar (Lamikanra *et al*. 2005a; Lamikanra and Watson 2007). This measures the percentage of O_2 and CO_2 in the gas sample. Respiration decreases the amount of O_2 and increases the

amount of CO_2 during storage. Since CO_2 and O_2 were inversely proportional, only the CO_2 will be reported and discussed.

Statistical Analysis

Standard error of mean values for non-sensory results was determined from standard deviation and sample size using GraphPad Prism (San Diego, CA) software for peroxidase activity and CO_2 emissions. The unpaired *t*-test with Welch correction was performed for comparison of means using GraphPad Instat software. Difference between mean values is considered significant when $P < 0.1$ instead of 0.05 because of wide variations between and among melons. Sensory data was analyzed using Proc Mixed in SAS, versus 9.1 (Cary, NC). Tukey's Studentized Range (HSC) Test was used to do mean comparisons of treatment effects.

RESULTS AND DISCUSSION

Microbial Assays

Cutting fruit underwater, with no calcium added, reduced the total microbial count relative to the control after 24 h storage (Table 1). Coliform, yeast and mold growth were also lower in underwater processed fruit for the same period of time. The microbial advantage of the underwater processed fruit, however, diminished with storage time. Total count was significantly lower in the submerged fruit until 7 days storage period ($P = 0.02$), unlike the coliform and yeast counts that were not significantly different from the control fruit counts. On day 10, microbial growth in both treated and control fruit pieces were comparable.

In the second experiment, the addition of calcium chloride in the treatment solution extended the effectiveness of the underwater cutting process in inhibiting microbial growth. Total count was significantly lower in cut cantaloupe pieces from submerged fruit until day 10 ($P = 0.0004$). Differences between mean counts of treated and control fruit in coliform, yeast and mold were significant over the 14 day storage period.

Calcium salts generally have suppressive effects on fungal growth, although it has been demonstrated that calcium may either have no effect or increase virulence of some fungal pathogens (Saftner *et al*. 1997; Biggs 2004). An important factor in the ability of calcium to inhibit fungal growth is related to the ability of calcium ions to associate with pectic substances, resulting in the thickening of fungal cell walls (Chardonnet *et al*. 1999). Coliform bacteria plate counts can also be reduced with the use of calcium as a processing aid (Escueta and Villa 1985; Kuyper *et al*. 1993). Calcium ions are well known to

TABLE 1.
MICROBIAL GROWTH (Log cfu/g) DURING STORAGE OF UNDERWATER CUT AND AEROBICALLY CUT CANTALOUPE MELON 4C

	Total count		Coliform		Yeast		Mold	
	Aerobic cut	UW cut	Aerobic cut	UW cut	Aerobic cut	UW cut	Aerobic cut	UW cut
Without calcium								
Day 1	4.97 (0.11)*	2.58 (0.44)	3.21 (0.04)	2.0 (0.15)	1.84 (0.58)	1.00 (0)	1.69 (0.87)	nd†
Day 7	6.61 (0.27)	5.12 (0.32)	2.28 (0.28)	2.5 (0.139)	4.03 (0.285)	2.99 (0.05)	1.26 (0.14)	nd
Day 10	6.69 (0.30)	6.61 (0.85)	2.41 (0.41)	2.47 (0.28)	4.51 (0.51)	3.30 (0.30)	1.00 (0)	nd
Day 14	6.99 (0.15)	6.72 (0.54)	4.55 (0.85)	5.93 (0.08)	4.82 (0.45)	3.30 (1.18)	1.03 (0.15)	nd
With calcium								
Day 1	2.94 (0.18)	1.70 (0.10)	2.33 (0.20)	1.69 (0.25)	1.1 (0.10)	0.77 (0.42)	1.46 (0.87)	nd
Day 7	4.45 (0.34)	2.77 (0.80)	3.38 (0.11)	0.84 (0.86)	1.97 (0.50)	0.89 (0.10)	1.56 (0.18)	nd
Day 10	4.70 (0.106)	1.30 (0.30)	3.78 (0.23)	0.82 (0.06)	3.21 (0.62)	0.77 (0.42)	1.1 (0.10)	nd
Day 14	6.01 (0.10)	3.45 (1.23)	3.4 (0.26)	1.97 (0.30)	1.1 (0.10)	nd	0.4 (0.43)	nd

* Standard error.
† None detected.

be involved in wound signaling mechanism (Poovaiah 1993). The microbial counts in control samples of the calcium experiment were generally lower than control fruit in the noncalcium treated underwater processed fruit, which may indicate that having calcium in the water during that first cut may decrease the microbial load during subsequent cutting in air. Lactic acid bacteria were not detectable in both underwater processed (calcium and non-calcium) and control samples. The low temperature of fruit storage (10C) apparently inhibited the growth of the typically mesophilic lactic acid bacteria (Lamikanra and Watson 2000; Lamikanra *et al*. 2000, 2005a).

Color Analysis

The tristimulus L^* and b^* values increased with storage in all fruit. The a^* values did not differ as a result of the experimental treatments (data not shown). This means that the fruit became lighter and more yellow in color during storage. At 10 and 14 days storage, L^* values were significantly higher (fruit was whiter) in treated fruit with calcium added to the water than the corresponding aerobic cut fruit (Table 2). There were no significant differences in b^* value between the aerobic cut and underwater cut fruit at each storage day. There was no significant change in the a^* value for any treatments; and it did not change over storage days (data not shown). The translucency intensity was not significantly different between the aerobic and underwater cut fruit for any days of storage in the no calcium experiment. In the experiment with calcium chloride added to the water, the fruit stored for 14 days was markedly ($P = 0.089$) less translucent in the underwater cut melon. In the calcium-treated water experiment, there was little change in translucency during storage for the aerobic cut and no change for the underwater cut. Meanwhile, the no–calcium-treated fruit (both aerobic and underwater cut) became more translucent during storage. This indicates that the calcium chloride added to the water reduced the translucency, whether only the first cut or all the cutting is accomplished underwater. The calcium seems to slow the wound signals and maintain the cell membranes.

Sensory Evaluation

Sensory assessment of fruit indicated decreases in some desirable sensory descriptors such as fruity melon and increases in off flavors (sour taste, rancid/painty and fermented aromas) with storage of cut fruit pieces at 10C (Table 3). Underwater cutting (with and without added calcium) helped retain the fruity/melon aroma slightly better than melons cut conventionally in air. Development of rancid/painty and fermented aromas during storage was less in underwater cut melons than air cutting. The development of sour taste had the least increase in the melons cut under water with added calcium chloride.

TABLE 2.
APPEARANCE OF CANTALOUPE MELON DURING STORAGE OF UNDERWATER CUT AND AEROBICALLY CUT FRESH-CUT FRUIT

	Appearance					
	Translucency		Lightness (*L*)		*b**	
	Aerobic cut	UW cut	Aerobic cut	UW cut	Aerobic cut	UW cut
Without calcium						
Day 1	1.7 (0.41)†	1.8 (0.44)	56.6 (1.09)^{B}	57.3 (0.93)	19.3 (0.22)^{B}	18.9 (0.41)^{B}
Day 7	1.4 (0.34)	1.6 (0.17)	65.4 (0.78)^{A}	63.1 (1.12)	25.6 (0.56)^{A}	26.8 (0.56)^{A}
Day 10	2.5 (0.96)	3.4 (1.03)	64.0 (1.07)^{A}	56.1 (3.59)	26.1 (0.56)^{A}	23.8 (1.57)^{A}
Day 14	3.0 (0.59)	3.2 (0.61)	62.3 (0.65)^{AB}	58.5 (3.34)	24.0 (1.46)^{A}	24.6 (1.49)^{A}
With calcium						
Day 1	2.0 (0.25)	1.9 (0.23)	45.1 (0.39)^{B}	44.5 (0.76)^{B}	17.2 (0.31)^{B}	17.4 (0.39)^{B}
Day 7	2.3 (0.54)	2.26 (0.59)	63.1 (0.95)^{A}	64.4 (0.71)^{A}	26.5 (0.4)^{A}	27.6 (0.6)^{A}
Day 10	2.5 (0.38)	2.03 (0.51)	62.6 (0.62)^{bA}	64.9 (0.79)^{aA}	27.1 (0.56)^{A}	26.5 0.48)^{A}
Day 14	2.7 (0.38)	1.69 (0.41)	62.3 (0.93)^{bA}	64.8 (0.6) ^{aA}	27.1 (0.23)^{A}	26.7 (0.45)^{A}

† Standard error.

^{a,b} Significant mean comparison (Tukey's Studentized Range [HSD] Test) between (across) control and experimental treatments within a day of storage (1, 7, 10 or 14 days).

^{A,B} Significant mean comparison (Tukey's Studentized Range [HSD] Test) between (down) days of storage within a treatment (aerobic cut or underwater cut).

TABLE 3.
SENSORY QUALITY OF CANTALOUPE MELON DURING STORAGE OF UNDERWATER CUT AND AEROBICALLY CUT FRESH-CUT FRUIT

	Aroma					
	Fruity/melon aroma		Fermented		Rancid/painty	
	Aerobic cut	UW cut	Aerobic cut	UW cut	Aerobic cut	UW cut
Without calcium						
Day 1	3.3 (0.8)*	3.4 (0.61)	0	0.1 (0.13)	0^{B}	0^{B}
Day 7	1.4 (0.5)	2.3 (0.91)	1.2 (0.55)	0.3 (0.29)	$0.6\ (0.43)^{AB}$	0^{B}
Day 10	1.2 (0.44)	2.0 (0.85)	1.1 (0.58)	0.7 (0.39)	$0.8\ (0.37)^{AB}$	$0.5\ (0.19)^{AB}$
Day 14	0^{b}	$0.8\ (0.25)^{a}$	1.9 (0.78)	1.3 (0.56)	$1.5\ (0.24)^{A}$	$1.0\ (0.24)^{A}$
With calcium						
Day 1	2.5 (0.63)	2.9 (0.86)	0.3 (0.29)	0.3 (0.29)	0^{B}	0.3 (0.29)
Day 7	2.4 (0.38)	2.6 (0.70)	0.3 (0.29)	0.3 (0.17)	$0.1\ (0.07)^{B}$	0.1 (0.14)
Day 10	1.7 (0.61)	2.6 (0.47)	0.4 (0.43)	0.3 (0.29)	$0.1\ (0.07)^{B}$	0.3 (0.20)
Day 14	1.9 (0.60)	2.4 (0.68)	0.9 (0.34)	0.6 (0.37)	$1.2\ (0.55)^{aA}$	0^{b}
	Taste					
	Sweet taste		Sour taste		Fruity/Melon	
	Aerobic cut	UW cut	Aerobic cut	UW cut	Aerobic cut	UW cut
Without calcium						
Day 1	3.1 (0.60)	2.5 (0.56)	0.4 (0.27)	0.8 (0.31)	3.5 (0.60)	2.9 (0.44)
Day 7	2.2 (0.59)	1.9 (0.35)	1.2 (0.46)	0.7 (0.29)	1.6 (0.58)	2.9 (0.53)
Day 10	2.3 (0.65)	2.4 (0.56)	1.4 (0.42)	1.3 (0.37)	1.9 (0.67)	2.0 (0.73)
With calcium						
Day 1	2.5 (0.62)	2.4 (0.54)	0.7 (0.25)	0.3 (0.18)	2.3 (0.41)	1.9 (0.34)
Day 7	2.6 (0.37)	2.2 (0.51)	0.8 (0.35)	0.3 (0.23)	2.8 (0.60)	2.5 (0.70)
Day 10	2.5 (0.58)	2 (0.45)	1 (0.44)	0.4 (0.18)	1.8 (0.19)	1.3 (0.32)
Day 14	1.6 (0.44)	2 (0.40)	1.8 (0.41)	0.9 (0.4)	1.7 (0.46)	1.9 (0.48)
	Texture					
	Hardness		Moisture release		Crispness	
	Aerobic cut	UW cut	Aerobic cut	UW cut	Aerobic cut	UW cut
Without calcium						
Day 1	4.9 (0.45)	4.4 (0.52)	7.3 (0.99)	6.6 (1.01)	4.5 (0.74)	4.1 (0.91)
Day 7	4.5 (0.42)	4.3 (0.58)	6.0 (1.19)	6.6 (1.22)	4.1 (0.52)	4.3 (0.63)
Day 10	5.0 (0.47)	4.5 (0.34)	6.8 (1.27)	7.4 (1.05)	4.5 (0.80)	4.2 (0.71)
With calcium						
Day 1	4.1 (0.58)	4.3 (0.52)	6.7 (0.78)	6.7 (0.9)	3.7 (0.81)	3.7 (0.70)
Day 7	3.9 (0.4)	4.6 (0.35)	8.4 (0.97)	6.4 (1.21)	3.8 (0.71)	5.1 (0.71)
Day 10	3.4 (0.51)	5.2 (0.31)	7.1 (1.2)	5.7 (0.87)	3.0 (0.52)	4.0 (0.60)
Day 14	4.4 (0.60)	5.1 (0.25)	8.3 (1.2)	7.0 (0.98)	4.4 (0.68)	4.6 (0.41)

* Standard error.

[a,b] Significant mean comparison (Tukey's Studentized Range [HSD] Test) between (across) control and experimental treatments within a day of storage (1, 7, 10 or 14 days).

[A,B] Significant mean comparison (Tukey's Studentized Range [HSD] Test) between (down) days of storage within a treatment (aerobic cut or underwater cut).

The addition of calcium chloride to the water showed an improvement in preserving the fresh aroma during storage, over using only water for underwater cutting. Sweet taste, a very important taste in consumer acceptance of melons, decreased slightly less in cantaloupe cut under water.

The main textural difference identified by panelists between the treated fruit (with and without calcium present in treatment water) and untreated control fruit is the decreased moisture release after 1 day storage. *P* values for general mean difference between treated fruit and control storage was 0.024 in the absence of calcium. In the calcium-treated water, moisture release was more intense in the air cut (7.6) than in the underwater cut (6.4) samples (across all storage days). The samples processed in plain water (6.8) were no different than the air cut samples (6.7), but the storage day 14 samples were not included. Moisture release, an indication of the amount of wetness/juice released from the sample (Bett 2002), generally decreased with storage time in untreated control fruit.

Calcium chloride caused an increase in sensory hardness, where water alone did not change hardness. Lamikanra and Watson (2007) did not observe an increase in instrumental hardness in melons heated in calcium lactate treated water over fruit heated in plain water. Typically calcium salts increase hardness in fruits and vegetables. Lamikanra and Watson (2007) probably did not see an increase in instrumental hardness because the calcium lactate did not penetrate the rind of the melon during the heat treatment.

Peroxidase Enzyme Activity

Peroxidase enzymes in cantaloupe melon are of the ascorbate nature (Lamikanra and Watson 2001). Ascorbate peroxidase could be indicative of oxidative stress in plant tissues (Kampfenkel *et al*. 1995; Gueta-Dahan *et al*. 1997). An increase in enzyme activity as a result of fresh-cut processing and storage would be a manifestation of the stress level. Peroxidase under such condition would act to reduce potential oxidative damage to the fruit. It has been suggested (Lamikanra and Watson 2001, 2002) that post cut treatments of fresh-cut cantaloupe melon that reduces POD activity would extend product shelf life. Underwater processing in the absence of calcium ions did not affect POD activity (Fig. 1). In the presence of calcium, however, enzymatic activity was considerably increased. The increase also occurred in the control half of fruit initially cut in the calcium solution before cutting into cubes in air.

Calcium ions would normally reduce POD activity in enzyme extracts from cantaloupe melon (Lamikanra and Watson 2000). In a recent report (Lamikanra *et al*. 2005b), modification of wound signals during processing by placing cantaloupe melon under a UV-C light source while being cut caused an increase in POD activity. The increase was attributed to the induction of a

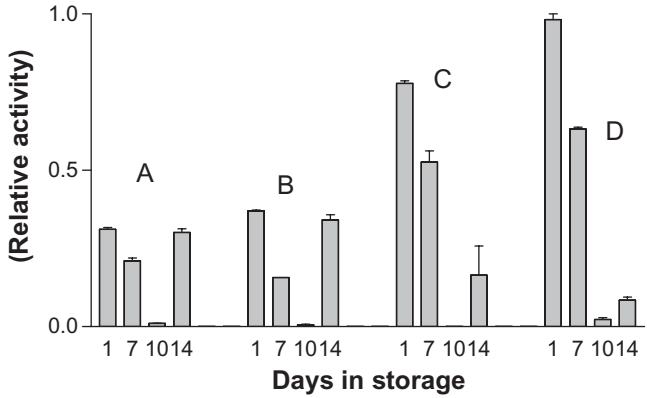

FIG. 1. PEROXIDASE ACTIVITY OF UNDERWATER AND AEROBICALLY PROCESSED FRESH-CUT CANTALOUPE MELON DURING STORAGE
A = fruit processed in open air, B = fruit processed underwater, C = fruit initially sliced in calcium solution before processing in open air and D = fruit processed in calcium solution.

hypersensitive defense response by UV that resulted in increased accumulation of POD. The role of calcium in signal transduction apparently causes a similar hypersensitive defense response that results in the disproportionate production of POD relative to the amount of inflicted wound.

Respiration

Storage temperature of cut fruit will influence product shelf life. Storage of cubed muskmelon at 10C caused over threefold increases in respiration rates over those that were stored at 0C (Toivonen and DeEll 2002). While 4C is an ideal storage temperature for fresh-cut cantaloupe melon, storage at higher refrigerated temperatures commonly occurs. The effect of underwater processing on respiration of cut fruit during storage at 10C was determined. After 10 days, headspace CO_2 was 18.3% for the control fruit stored at 10C (Fig. 2). Underwater processing, however, caused a reduction of 31% in headspace CO_2 in fruit stored at 10C. Hydraulic control of turgor, modulated by the intensity of respiration exists in cells apparently by way of a mechanism similar to that of osmoregulation (Cailloux and Do 1998). Changes in respiration and turgor during storage may also result from deterioration of cellular structure and rigidity (Di Matteo *et al*. 1998). The presence of dissolved calcium in the treatment water did not have an effect on respiration in fruit stored at 10C. The post-cut treatment of cantaloupe melon in calcium solution reduces the respiration rate of the cut fruit during storage at 10C (Lamikanra and Watson 2004). This reduction in reduced respiration was suggested to be

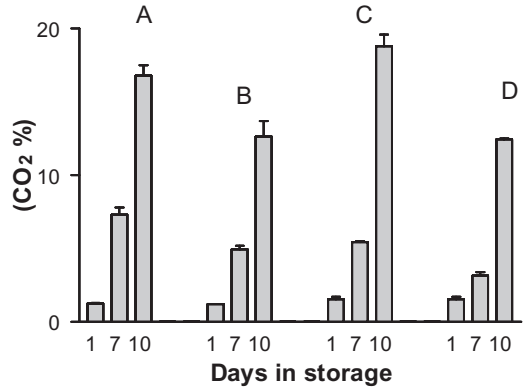

FIG. 2. CO_2 EMISSION OF UNDERWATER AND AEROBICALLY PROCESSED FRESH-CUT CANTALOUPE MELON DURING STORAGE
A = fruit processed in open air, B = fruit processed underwater, C = fruit initially sliced in calcium solution before processing in open air and D = fruit processed in calcium solution.

related to the covalent crosslinking properties of calcium and the consequent conferment of rigidity to tissue components. The lack of effect of calcium when present in underwater processed fruit, and the difference between the effect of calcium ions on POD in underwater and post cut applications may indicate a different role of the salt in the underwater processed fruit. It appears as if during storage at 10C, as a result of the change in difference in turgor during processing, the signal transduction effect of calcium is dominant in the former, while in post cut calcium application interaction between calcium and pectic substances predominate. The presence of calcium during underwater processing, however, only slightly reduced respiration during storage relative to the underwater processed fruit without the salt. The reduced respiration in post-cut treatments apparently results from increased covalent crosslinking and ability to facilitate gel formation by calcium ions at lower temperatures (Chronakis 1996; Choi *et al*. 1998; Lamikanra and Watson 2004).

CONCLUSION

Cantaloupe melon when submerged in water during cutting reduced microbial growth during the first few days of storage of the cut fruit, but has minimal advantage over the traditional cutting process when stored for prolonged periods of time. Dissolved calcium in the treatment water will reduce microbial growth relative to the open air cut fruit during refrigerated storage. Calcium also stabilized translucency of cut fruit during storage. Underwater

cutting in calcium treated water increased the moisture release attribute of cut cantaloupe melon during storage over air-cut fruit. The water without calcium displayed no differences. Under water cutting (with and without calcium) helps to retain the desirable flavors and slows the development of undesirable flavors slightly better than air cutting. Peroxidase activity increased in underwater processed fruit apparently as a consequence of a hypertensive defense response. The presence of calcium in the processing fluid elevated this effect. Respiration of cut fruit from underwater processed cantaloupe melon in the presence and without calcium present in solution was reduced by comparable ratios to their respective control fruit during storage.

REFERENCES

BEGUIN, G., CLAEYS, G. and DELAVET, C. 1996. Procédé et dispositif de découpe de légumes et de fruits. French Patent No. 95 04674.

BETT, K.L. 2002. Evaluating sensory quality of fresh-cut fruits and vegetables. In *Fresh-Cut Fruits and Vegetables: Science, Technology and Market* (O. Lamikanra, ed.) pp. 427–438, CRC Press, Boca Raton, FL.

BIGGS, A.R. 2004. Effect of inoculum concentration and calcium salts on infection of apple fruit by *Botryosphaeria dothidea*. Plant Dis. *88*, 147–151.

CAILLOUX, M. and DO, C.B. 1998. Osmoregulation and water regulation in protoplasts of the radish tubers (Raphanus sativus). Can. J. Bot. *76*, 1835–1842.

CARIDIS, A.A., SILVESTER, J., BROWN, D.E., MURGEL, L.P., BELT-SAYADEH, C., CARIDIS, A.A. and MORRIS, A.W. 2002. Simultaneous slicing and washing of vegetables. United States Patent 6,413,566.

CHARDONNET, C.O., SAMS, C.E. and CONWAY, W.S. 1999. Calcium effect on the mycelial cell walls of Botrytis cinerea. Phytochemistry *52*, 967–973.

CHOI, M.J., HWANG, C.S. and MANGINO, M.E. 1998. The effect of pretreatment on increasing gel strength of whey protein concentrates. *Whey*: Proceedings of the Second International Whey Conference, pp. 172–180.

CHRONAKIS, I.S. 1996. Network formation and viscoelastic properties of commercial soy protein dispersions: Effect of heat treatment, pH and calcium ions. Food Res. Int. *29*, 123–134.

DI MATTEO, M., CIAMBELLI, P., CINQUANTA, L. and PALO, M. 1998. Storage of head Ninja lettuce (*Lactuca sativa* L.) in modified atmosphere packaging. Italus Hortus. *5*(5–6), 18–22.

ESCUETA, E.E. and VILLA, T.M. 1985. Chemical microbiological and sensory studies of conveniently packaged soy curd (taho) in cups. Philippine-Agriculturist *68*, 124–129.

FERGUSON, I.B. 1984. Calcium in plant senescence and fruit ripening. Plant Cell Environ. *7*, 477–489.

GARCIA, E. and BARRETT, D.M. 2002. Preservative treatments for fresh-cut fruits and vegetables. In *Fresh-Cut Fruits and Vegetables: Science, Technology and Market* (O. Lamikanra, ed.) pp. 267–304, CRC Press, Boca Raton, FL.

GUETA-DAHAN, Y., YANIV, Z., ZILINSKAS, B.A. and BEN-HAYYISM, G. 1997. Salt and oxidative stress: Similar and specific responses and their relation to salt tolerance in citrus. Planta *203*, 460–469.

HERDE, O., PENA-CORTES, C.H., WILLMITZER, L. and FISAHN, J. 1998. Time-resolved analysis of signals involved in systemic induction of Pin2 gene expression. Bot. Acta *111*, 383–389.

KAMPFENKEL, K., VON MONTAGUE, M. and INZE, D. 1995. Effects of iron excess on *Nicloiana Plumbaginifolia*. Implications to oxidative stress. Plant Physiol. *107*, 725–735.

KUYPER, L., WEINERT, I.A.G. and MCGILL, A.E.J. 1993. The effect of modified atmosphere packaging and addition of calcium hypochlorite on the atmosphere composition, colour and microbial quality of mushrooms. Lebensm.-Wiss. Technol. *26*, 14–20.

LAMIKANRA, O. and WATSON, M.A. 2000. Cantaloupe melon peroxidase: Characterization and effects of food additives on activity. Nahrung *44*, 168–172.

LAMIKANRA, O. and WATSON, M.A. 2001. Effects of ascorbic acid on peroxidase and polyphenoloxidase activities in fresh-cut cantaloupe melon. J. Food Sci. *66*, 1283–1286.

LAMIKANRA, O. and WATSON, M.A. 2002. Biochemical changes associated with fresh-cut fruit processing and storage. In *Freshness and Shelf Life of Foods* (K.R. Cadwallader and H. Weenen, eds.) ACS Symposium Series 838, pp. 52–69, American Chemical Society, Washington, DC.

LAMIKANRA, O. and WATSON, M.A. 2004. Effect of calcium treatment temperature on fresh-cut cantaloupe melon during storage. J. Food Sci. *69*, C468–C472.

LAMIKANRA, O. and WATSON, M.A. 2007. Mild heat and calcium treatment effects on fresh-cut cantaloupe melon during storage. Food Chem. *102*, 1383–1388.

LAMIKANRA, O., CHEN, J.C., BANKS, D. and HUNTER, P.A. 2000. Biochemical and microbial changes during the storage of minimally processed cantaloupe. J. Agric. Food Chem. *48*, 5955–5961.

LAMIKANRA, O., BETT-GARBER, K.L., INGRAM, D.A. and WATSON, M.A. 2005a. Use of mild heat pre-treatment for quality retention of fresh-cut cantaloupe melon. J. Food Sci. *70*, C53–C57.

LAMIKANRA, O., KUENEMAN, D., UKUKU, D. and BETT-GARBER, K.L. 2005b. Effect of processing under ultraviolet light on the shelf life of fresh-cut cantaloupe melon. J. Food Sci. *70*, C534–C539.

MALONE, M. and STANKOVIC, B. 1991. Surface potentials and hydraulic signals in wheat leaves following localized wounding by heat. Plant Cell Environ. *14*, 431–436.

MEILGAARD, M., CIVILLE, G.V. and CARR, B.T. 2007. *Sensory Evaluation Techniques*, 4th Ed., CRC Press, Boca Raton, FL.

POOVAIAH, B.W. 1993. Biochemical and molecular aspects of calcium action. Acta Hortic. *326*, 139–147.

SAFTNER, R.A., CONWAY, W.S. and SAMS, C.E. 1997. Effects of some polyamine biosynthesis inhibitors and calcium chloride on in vitro growth and decay development in apples caused by Botrytis cinerea and Penicillium expansum. J. Am. Soc. Hort. Sci. *122*, 380–385.

SHIMMEN, T. 2001. Electrical perception of "death message" in Chara: Involvement of turgor pressure. Plant Cell Physiol. *42*, 366–373.

STAHLBERG, R. and COSGROVE, D.J. 1995. Comparison of electric and growth responses to excision in cucumber and pea seedlings. II. Long-distance effects are caused by the release of xylem pressure. Plant Cell Environ. *18*, 33–41.

STANKOVIC, B., ZAWADZKI, T. and DAVIES, E. 1997. Characterization of the variation potential in sunflower. Plant Physiol. *115*, 1083–1088.

TOIVONEN, P.M.A. and DEELL, R. 2002. Physiology of fresh-cut fruits and vegetables. In *Fresh-Cut Fruits and Vegetables: Science, Technology and Market* (O. Lamikanra, ed.) pp. 91–123, CRC Press, Boca Raton, FL.